general health of the exhibits. The secretary also realised that in the past, when new buildings and enclosures were erected, in most cases immediate convenience took precedence of any general scheme. In 1909 he induced the council to consider the condition of the gardens with regard to existing buildings of a permanent character, and recommended that in the future, as buildings and enclosures were erected, they should be arranged in conformity with a general plan. The matter was temporarily shelved, but in 1912 the garden committee drew up a list of the animals the society could expect to exhibit under suitable conditions at any time, considered the existing accommodation, deciding how far it was to be regarded as satisfactory, and what areas should be reserved for the supply of further accommodation as it could be provided. It is in conformity with the plan then drawn up that the various buildings and open spaces provided in recent years have been erected and set out.

In 1906 and in 1907 the society obtained additional grants of land from H.M. Commissioner of Works. The 20 acres of land granted to the society in 1826 lay on both sides of the Outer Circle, corresponding roughly with the existing middle and south gardens, but only a portion to the south of the circle was laid out. In 1834 an additional plot of ten acres on the south-west border of the gardens was obtained at an annual rental, on the condition that it was to be used as pasturage. In 1839, use of the land north of the Regent's Park Canal, corresponding to the existing north gardens, was granted.

In 1841 the ground in the occupation of the society was rearranged. The strip on the north bank of the canal was surrendered, and a portion at the east end of the middle garden was exchanged for a corresponding area at the west end, and permission was given to extend the works over the ten acres granted in 1834. In 1869 the land on the north bank of the canal was again taken over by the society. A considerable portion of the north garden was, however, not made use of until after 1903, when the policy of increasing open-air facilities for the animals was put into operation. Complete use of the north garden was, however, not possible until 1906, when the right-of-way was obtained over two unoccupied portions of ground on both sides of the canal, and H.M. Commissioner of Works agreed to allow half of the new bridge over the canal to be used by the society on payment of its proportion of the cost of reconstruction. A communication between the north and the middle gardens was thus obtained. In 1907 a strip of ground was obtained along the south-west boundary of the south garden, which ends in a large triangular area at the west end, now occupied by a pond for water-fowl, and goose paddocks. The condition attached to the grant of the new piece of land was that the animals placed on it should be visible to the public in Regent's Park. The paddocks erected on this site now contain deer, llamas, emus, and rheas.

Of the buildings erected and designed under supervision of the present secretary, the Small Cats' House (1903), the Sea-Lions' Pond (1905), the Small Birds' House (1905), the Cattle and Deer Sheds (1906), the Society's New Offices and Library (1909), the Sanatorium (1909), the New Prosectorium (1909), the Mappin Terraces for the open-air display of mountain goats and bears, with its tea-pavilion (1913), the Small Mammal and Caird Insect House (1913), and the New Tea Pavilion facing the broad walk (1922), are the most important. The transfer of the offices, library, and meeting room to the gardens, apart from providing adequate accommodation for the library, which had outgrown the rooms in Hanover Square, has greatly facilitated the work of the staff. At the time there was some opposition to the transfer, a few fellows being of opinion that there would be a falling off in the attendances at the scientific meetings. Such, however, has not been the case, as at the present day they are attended far better than in the past.

How all the great improvements which have gradually been effected during the past twenty years have popularised the gardens may be best realised when we consider that the admissions, which in 1902 amounted to less than 700,000, last year exceeded 1,500,000. When the new fresh-water and marine aquarium, which the council has decided to build under the Mappin Terraces, is completed, the latter figure will no doubt be exceeded.

The Resonance Theory of Audition.

By Prof. E. H. BARTON, F.R.S.

THE resonance theory of audition continues to excite considerable interest and must be regarded as being still in the controversial stage. The very name is somewhat unfortunate and may have led some into the mistaken view that some sympathetic vibrators in the ear are postulated as capable of actual resonance or resounding like a tuning-fork set in audible vibration by another which was first sounded. Of course it should be understood, on the resonance theory, that the vibrator in question merely vibrates when a sound of nearly its own proper pitch is received by the ear, such vibration, though effecting audition by its possessor, being quite inaudible to others. Some through misunderstandings on this or other points have failed to grasp the essentials of the resonance theory of audition, and have in consequence levelled at it criticisms which clearer knowledge on their part would have obviated. No attempt will be made here to locate in the ear those mechanisms, if any, which play the part of sympathetic vibrators, responders, or resonators. That is left to the anatomists to discover. But we may note briefly the essentials of the resonance theory, the salient facts of audition and what power the theory has of meeting the demand which those facts make upon it. In the latter we may derive help from the consideration of a simple working model which any one may set up and experiment with for himself.

Essentials of the Resonance Theory.—This theory postulates the existence within the ear of some set of mechanisms, each of which has its own proper rate of vibration and rate of dying away when left to itself. Each such vibrator can accordingly be set in vigorous vibration by very feeble forces, provided they occur at or very nearly at the rate in question. These sympathetic vibrations would quickly die away when their stimulating cause ceased. Each such vibrator is supposed to have nervous connexion with the brain so that the fact and amplitude of its vibrations may be transmitted thence and duly noted.

The theory is not primarily concerned with the exact nature or details of structure of these vibrators provided only that they fulfil the foregoing conditions for mathematical theory shows that the response of one such vibrator to the forces exerted upon it by another vibration obeys the same general laws quite independently of the details and nature of the vibratory responder under consideration.

Facts of Audition.—For normal ears the following may be regarded as the chief facts of audition with which we are here concerned :

(i.) The range of audition is limited at the upper and lower ends, such limit varying with individuals, but about eleven octaves are usually audible.

(ii.) Before either limit of audition is reached the notes may be recognised to be very high or low, but the distinct location of pitch fails, so that only about seven octaves are musically available.

(iii.) At about the middle of the range the discrimination of pitch between near notes when sounded successively is, for a keen ear, about the twentieth of an equal-tempered semitone or $\frac{1}{240}$th of an octave.

(iv.) When two very near notes of almost equal intensities are sounded simultaneously, the difference of their frequencies may be recognised by any one as the number of beats per second. This may serve to discriminate a pitch-difference of the fortieth of a semitone or half that just named.

(v.) When two different notes at a considerable interval (say C and G) are sounded together, both notes can be heard and their interval estimated, they are not mistaken for a single note of intermediate pitch (E or E♭). (This deserves special notice as being the direct opposite of colour vision for some parts of the spectrum, and will be dealt with in another article.)

(vi.) When several simple vibrations occur simultaneously, being produced in association from the same vibrating source, string or wind, the resulting character of the compound tone or note is recognised and spoken of as its quality, quality of tone, or tone simply.

(vii.) A musical shake of about ten notes per second on a note of frequency about a hundred and ten per second can be heard distinctly.

Power of Theory to meet the Facts.—Having briefly reviewed the chief facts of audition we may now naturally ask what power the resonance theory has to meet the demands thus made upon it. In other words, can the physicist imagine a set of vibratory responders the behaviour of which under vibratory stimuli would give results which correspond to those of human audition ? In trying to arrive at a right or possible solution, obviously many variables are at our disposal. They may be stated thus :

(*a*) The total range of pitches of the set of responders.

(*b*) The musical intervals between adjacent responders.

(*c*) The damping (or rate of dying away) of the vibrations natural to these responders when started and then left to themselves.

(*d*) The constancy or otherwise of the intervals and of the dampings throughout the range.

(*e*) The fineness of discrimination of relative amplitudes of vibrations of adjacent or other responders by means of the nerves attached to them.

These variables are more than are needed to make a solution possible ; they leave a choice between a variety of possibilities which may be imagined by the physicist and suggested to the anatomist for examination and rejection or acceptance. Thus, for example, the less the damping natural to a set of responders the easier is the location of pitch by them. But the presence of objectionable damping could be balanced by an enhanced fineness in the nervous discrimination of relative amplitudes of adjacent responders. A word or two of explanation may be desirable as to the relation between the damping natural to a vibratory responder and the nature of its responses to various alternating forces of nearly its own frequency. Without entering here into the niceties of the mathematical theory it may be said broadly that the best response follows only with the best tuning between the frequency natural to a responder and that of the forces acting upon it. But the actual value of this response and its falling off consequent upon mistuning both depend on the damping natural to the responder. If the damping is very slight, then the response is very vigorous for precise tuning, but for quite small mistunings the response is almost negligible. This is often summed up by saying that for slightly damped responders the resonance is *sharp*. On the other hand, for highly damped responders the response is not so good for best tuning as in the former case, but this response is only slightly impaired by moderate mistuning of the forces. In other words, for strongly damped responders the resonance is *spread*.

Bearing these facts in mind we have to make a choice among the possibilities open to us so as best to meet the facts of the case. The facts (iii.) and (v.) show that the damping must not be too large, because that would involve spread resonance instead of the sharpness needed for the actual fineness of location of pitch experienced. On the other hand, fact (vii.) shows that the damping must not be too small, as in that case the sound heard from one note of the shake would run into that of the next and give a blurred effect contrary to experience. We have thus found limits between which the damping should lie.

In view of these considerations we may submit the following suggestions. Let it be supposed that in the ear there is a set of vibratory responders which—

1. Cover a range of seven or more octaves,
2. Are about twelve to the octave in the middle of the range and have a suitable damping,
3. Are in total number about a hundred.

Simple Model and its Behaviour.—To test the adequacy of the arrangement just postulated let the following simple model be set up as shown in the diagram, Fig. 1.

This responsive model consists essentially of a stout cord stretched across a room between the fixed points H and J, with a pendulum KL with heavy bob L to act as driver, and a number of light graduated responders lettered C to C′. The latter have small paper cones about 2 cm. high as bobs, with the addition of split rings of copper wire resting on them to prevent the damping being too great. The driving pendulum has a "tightener" at M to adjust its length, which must be reckoned from L up to N, since when the heavy bob L swings the bridle HKJ swings about the line HNJ. The lengths of the light responders, on the other hand, must be reckoned only up to their suspension point on the cord HK. These light responders have suspensions of thread which are passed through the cord HK and may then be cut off and the adjustment to place made so that the line of the bobs CD—C′ passes through H. This is essential in order that each responder receives an equal inclination by a given displacement of the heavy bob L. In the diagram just one octave of responders is shown, the number being thirteen and the lengths such as to make their relative frequencies those of the consecutive notes on the piano or organ. This allows a fineness of discrimination of pitch in agreement with experience. Of course to represent the whole set of aural mechanisms, seven or more octaves would be needed, but a single octave on the model enables one to carry out a number of interesting tests, though for some, two octaves are necessary, as shown by dotted lines in the figure. For the latter the lengths of the responders (and also the distances from H of their points of suspension) may be as follows: 57·05, 50·8, 45·25, 40·3, 35·9, 32·0, 28·5, 25·4, 22·6, 20·16, 18·0, 16·0, 14·25, 12·7, 11·3, 10·1, 9·0, 8·0, 7·13, 6·35, 5·65, 5·04, 4·49, 4·0, 3·55 cm. Any consecutive thirteen values will do for a single octave.

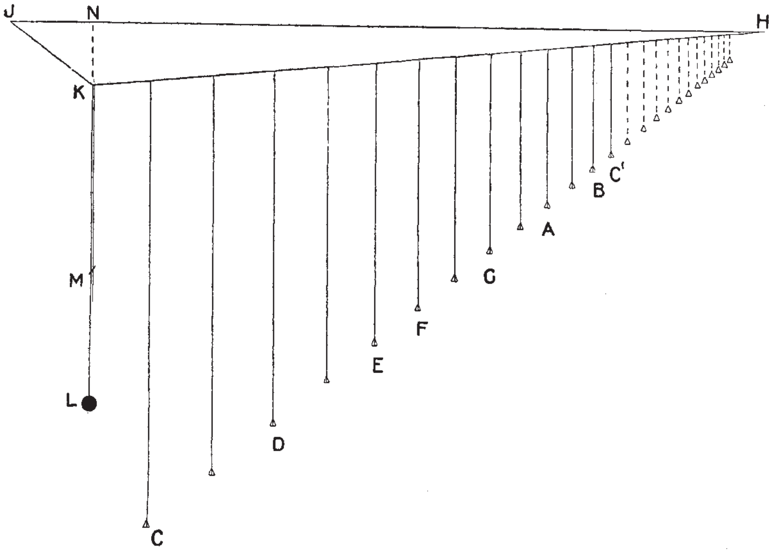

FIG. 1.

We may now test the behaviour of such a model and ascertain if in essential features it typifies the mechanism in the ear, although of course it is not for a moment imagined that any pendulums exist in the ear. If vibratory responders exist there they must be of an elastic nature.

If the seven octaves or more of responders were provided we should have the musical range of seven octaves accounted for. Further, the lack of precise discrimination of pitch for very high notes and for very low notes is explained also. Thus, for any note well within the range of the responders, when the pendulum bob L is swung, thus representing by its frequency a certain note, the responders vibrate in response, the one best in tune vibrating most, the others near it, *both above and below*, showing a rather less response. Hence the pitch is recognised and located by this behaviour. But if the pendulum LN is made shorter than the shortest or longer than the longest responder provided, then we have the responders near the end in question responding best but no maximum response with a *return to quiescence beyond it.* Thus the exact pitch cannot be located, and this agrees with experience. Consider next the discrimination of pitch between notes very near in pitch, and let us ascertain what is possible when the adjacent responders differ in pitch by a semitone or one-twelfth of an octave. It will be easily ascertained that a discrimination of pitch of about the twentieth of this semitone is possible. For by adjusting the tightener M on the suspension KL, we can make the response of two adjacent pendulums equal, and then by repeatedly lengthening the heavy or driving pendulum the response of the lower of the two light pendulums may be increased and that of the higher one decreased till the lower one just shows a maximum, the adjacent ones above and below being alike in their response. We should then have passed over the half of a semitone only and ten steps are susceptible of discrimination in this range. Without any wire rings on the paper cones the responders would not succeed in this test, but with the rings to weight the cones there is less damping, sharper resonance, and adequate discrimination.

If two octaves of responders are provided very striking experiments can be shown as to the recognition of the overtones essential to notes of a certain quality of tone. Thus, setting the pendulum NL to the pitch of a low responder, say the third from the bottom, if the pendulum swings freely we have a responsive maximum at that responder. But if the bob L is grasped in the hand and swung to and fro in the same period as before, but with a "dimple" at one end of the swing, it is really executing tone and octave, and the responders will promptly show the corresponding two resonance humps. Again, if the bob L is swung to and fro, with a "dimple" at each end, it is really executing tone and twelfth (frequencies 1 and 3), and the responders give the corresponding two resonances. Lastly, if the bob L is moved smoothly from end to end in one direction, but returns with two kinks or dimples, we have really a vibration consisting of tone, octave and twelfth (frequencies as 1, 2 and 3), and the three appropriate resonance humps are shown by the set of responders.

Thus, without overstraining or even exhausting the possibilities of the resonance theory it seems easy by its use to account for the main facts of audition, none of which seem in conflict with the theory. This, of course, does not suffice to establish the hypothesis, as it is conceivable that some other might be equally successful. But, pending the advent of such a rival, perhaps the disciples of Helmholtz may be pardoned for what others might style their inexplicable interest in an old and unproved theory.

The Lesser Whitethroat's Fanfare.

(To J. S. H.)

THOUGH lyrics mingled with tattoos
Of melodrama savour,
The Lesser Whitethroat dares to use
Both avenues to favour.
Behind a screen
Of leaves unseen
He'll croon with tenderest passion,
Then loudly reel
A clarion peal
Of notes in fanfare fashion :
(Sotto voce, pp.) *Chi′ddy-choo-ee′cheo,-Wee′jo-choo-ee′chey,*
Wee′-chiddy-wee′chey,-Choo-i′ddy, Choo-ee′ !
Then changing time,
And reckless of rhyme :
(*Vivace, ff.*) JIP-JIP-JIP-JIP,
JIP-JIP-JIP-JIP,
JIP-JIP !

But can we give this Warbler praise
When art he compromises,—
In secret hums his native lays,
And flash-notes advertises ?
Sing, Warbler, sing !
These cries you fling
Too soon all tune will smother ;
And then you'll flit
A ribald Tit,
And Whitethroats lose their brother !

W. GARSTANG.

Obituary.

W. H. HUDSON.

THE death of Mr. William Henry Hudson at his residence in London on August 18, in his eighty-first year, removes from our midst a remarkable personality, a great writer of English prose, and a keen interpreter of Nature.

Mr. Hudson's father emigrated to the Argentine in the early part of the last century and settled on the pampas, and it was there that his childhood and early life was spent. We get a vivid idea of the conditions under which he grew to manhood in the pages of "Far Away and Long Ago," a volume of autobiographical recollections which he published in 1918—the vast treeless plains, the solitary estancia with a few trees around it, the semi-savage gauchos, and above all the teeming bird life along the strand of a lonely mere.

In his early days Mr. Hudson entered into correspondence with the late Dr. P. L. Sclater and sent him collections of birds and mammals. Accounts of these, first appearing in the Proceedings of the Zoological Society, formed the foundation of a joint work, "Argentine Ornithology," published in two volumes in 1888-1889, to which Mr. Hudson contributed the notes and observations on the habits of the birds, while Dr. Sclater was responsible for the technical descriptions and general arrangement. This work was recently re-issued by Mr. Hudson alone, but without the technical descriptions, under the title of "Birds of La Plata." Two other volumes, well known to lovers of good writing dealing with South American Natural History, were "The Naturalist in La Plata," 1892, and "Idle Days in Patagonia," 1893.

About this time Mr. Hudson came to England and began a long series of works dealing with the study of Nature in England. "Birds of a Village," "Nature in Downland," "Hampshire Days," "The Land's End," and the more strictly ornithological "British Birds," "Birds and Man," and "Birds in London," followed one another in quick succession. Though always in feeble health and of a delicate constitution, he tramped over southern England from the New Forest to Penzance throughout the summer, spending the winter partly in London and partly at Penzance, where he made his second home.

Recognition of his talent came late to him. In his early days in England he was unable to earn a livelihood with his pen and he was awarded in 1901 a Civil List Pension of 150*l.* in "recognition of the originality of his writings on natural history." This he resigned in August last year on the ground that he needed it no longer. "Publishers," he told an intimate friend, "threw money at him with both hands."

A man of extremely sensitive temperament, Hudson could not endure to take the life of any animal or bird, and was an ardent supporter of the Society for the Protection of Birds, to which he devoted much of his energy during recent years. He was thus out of sympathy with any form of collecting. He had, however, a wonderful power of observation, and his sense of hearing was extremely acute. His writing is simple, lucid, and descriptive, and he never gave to his observations on bird or animal psychology that anthropomorphic tendency which so often characterises the writers of popular works on natural history subjects. Though he can never be reckoned among the ranks of scientific ornithologists, his writings will undoubtedly endure as monuments of accurate observation and of limpid, lucid, English prose.